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An Analysis Method to Nowcast Three-Dimensional Meteorological Data for the U.S. Army IMETS

by Teizi Henmi and Robert Dumais

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Army Research Laboratory

White Sands Missile Range, NM 88002-5501

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Computational and Information Sciences Directorate

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14. ABSTRACT

An analysis method for creating three-dimensional meteorological data was developed for the U.S. Army Integrated Meteorological System (IMETS) for the purpose of nowcasting. The method uses data regularly obtained from the U.S. Air Force Weather Agency, which includes numerical forecast data generated by the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model Version 5, along with routine surface and upper-air observations. The method is described in detail and, for the purpose of this study, applied to a region in the southeastern United States in order to demonstrate its general utility. The method is also applied to a region of Utah and evaluated statistically using local mesonet meteorological data.

15. SUBJECT TERMS

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Summary

An analysis method for creating three-dimensional meteorological data, developed in a previous study (Henmi, 2003), has been adapted for use by the U.S. Army Integrated Meteorological System for the purpose of nowcasting. This method uses data regularly obtained from the U.S. Air Force Weather Agency, which includes numerical forecast data generated by the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model Version 5 (MM5) (Grell et al., 1994), along with routine surface and upper-air (radiosonde) observations.

This report describes the method in detail, and then shows how it was applied to a region in the southeastern United States in order to demonstrate its general utility. Furthermore, the method (along with two others) was applied to a region of Utah and evaluated statistically using the local mesonet meteorological data. The three methods used to generate the statistical analyses over Utah were:

  a. A nowcast analysis using the present method, and using 15-km resolution MM5 output (nest 2 of a triple-nested configuration) as background data

  b. A pure forecast produced by the MM5, nest 3 (5-km grid resolution)

  c. A nowcast analysis using the Battlescale Forecast Model nudging method (Henmi and Dumais, 1998) and 15-km resolution MM5 forecast output as background data.

For the Utah domain, each method was statistically compared for both a summer (2003) and a winter (2004) period. For each method, a final analysis of 5-km resolution was generated.

Both of the nowcasting methods (a and c) produced much better statistical results for temperature, dew-point temperature, and wind vectors for the 5-km resolution Utah domain, as compared to pure forecast method (b), produced by the MM5 5-km resolution nest. However, all three methods showed limited capabilities in simulating the high-resolution wind fields.

1. Introduction

The U.S. Army's Integrated Meteorological System (IMETS) regularly receives gridded binary data (GRIB) of forecast results from the U.S. Air Force Weather Agency (AFWA), computed by an AFWA operational version of the Pennsylvania State University/National Center for Atmospheric Research (NCAR) Mesoscale Model Version 5 (MM5). The forecast data are produced for model domains of both 15- and 45-km grid resolution (and occasionally 5-km resolution), and are generally reliable in terms of forecast accuracy. However, the forecasts can sometimes evolve far from reality (Henmi, 2002 and 2003).

For Army operations, accurate meteorological information, obtained by making maximum use of currently observed local data, is more desirable than information that relies on fields obtained by a previously executed numerical forecast model. Nowcasting is a method of diagnosing the current weather situation. In this study, nowcasting is further defined as an objective analysis of meteorological parameters that have been currently observed. If the current weather situation can be accurately diagnosed, it may be possible to accurately forecast or extrapolate near-future weather situations.

In a previous study (Henmi, 2003), a nowcasting method that allows for the rapid updating of three-dimensional meteorological fields was developed and discussed. In this method, surface and upper-air meteorological fields are analyzed, both independently and univariately. In other words, the surface observations and the corresponding MM5 surface forecast data are composed using the successive correction method (Sashegyi and Madala, 1994), and the upper-air radiosonde data and the MM5 sigma-p level forecast data are similarly composed using the same scheme. After these two steps, the similarity theory formulae, MARIAH (Rachele et al., 1995), are used to combine the surface data analysis fields with the upper-air data analysis fields. The analyses must be interpolated both horizontally (onto the analysis i, j space) and vertically (onto the analysis terrain-following sigma-z levels).

The purpose of the present study is to apply and adapt the aforementioned nowcasting method to a pseudo-IMETS operational environment and to statistically evaluate the method by using Utah MesoWest data (Horel et al, 2002). Section 2 describes the nowcasting method and section 3 presents an example of the method application. Section 4 outlines the results of a statistical evaluation of the nowcasting method for a domain over Utah, comparing it to results from two other methods. The concluding remarks follow in section 5.

2.   Nowcast Analysis

2.1   Data Used

MM5 forecast data, along with surface and upper-air meteorological observations, are received and added into a database in the current, operational IMETS. The nowcast analysis method discussed here is designed to perform computation using these types of data. The data that were used in this study are discussed below.

Data obtained for 1200 universal time coordinated (UTC) on April 12, 2004 (in the southeastern United States) are used in the following examples.

2.1.1 MM5 Data

Using GRIB MM5 forecast fields sent from AFWA, vertical distributions of forecast data (per grid point and native sigma-P level) are reduced, as shown in figure 1.

32.142						
-87.327						
73.98	18162.70	18211.70	207.50	12.88	11.20	6.40
91.01	16892.10	16941.10	211.70	15.20	12.10	10.20
108.87	15771.19	15820.19	215.70	17.51	21.40	8.80
128.13	14738.37	14787.37	216.70	17.45	32.80	18.00
148.68	13794.75	13843.75	216.80	15.09	32.40	25.70
170.58	12921.76	12970.76	216.40	12.91	27.50	31.60
193.94	12106.34	12155.34	217.60	14.56	21.70	34.70
218.54	11338.97	11387.97	220.90	17.05	19.90	33.70
244.34	10612.42	10661.42	223.60	14.28	24.00	28.60
271.33	9921.12	9970.12	226.50	11.88	29.00	24.00
299.48	9260.63	9309.63	230.40	13.67	31.40	21.10
328.17	8637.39	8686.39	234.60	19.33	31.10	19.10
357.81	8037.11	8086.11	239.10	11.32	30.00	17.50
387.89	7466.34	7515.34	243.60	19.40	28.40	15.90
418.39	6921.62	6970.62	247.50	22.49	27.20	14.10
448.87	6407.90	6456.90	251.10	25.55	25.90	11.80
479.30	5921.57	5970.57	254.90	25.48	24.50	10.10
509.64	5459.61	5508.61	258.70	30.00	23.00	9.40
539.93	5019.51	5068.51	261.60	25.74	20.80	9.50
570.22	4599.12	4648.12	264.20	14.44	18.60	9.80
600.46	4196.63	4245.63	266.90	7.70	16.50	9.90
630.72	3810.44	3859.44	268.60	2.68	12.90	8.80
661.07	3439.18	3488.18	269.50	0.00	9.70	8.30
691.45	3081.65	3130.65	272.20	0.06	9.10	8.40
721.77	2736.80	2785.80	274.60	0.40	8.30	9.00
751.10	2413.92	2462.92	277.00	0.81	7.90	9.30
779.42	2111.22	2160.22	279.20	1.00	7.30	9.50
806.29	1831.98	1880.98	281.10	1.28	6.60	9.80
831.69	1574.49	1623.49	283.10	2.12	5.90	10.10
854.75	1346.44	1395.44	283.50	0.26	4.60	9.70
876.41	1136.97	1185.97	284.80	0.32	4.50	9.50
896.21	949.46	998.46	285.20	0.00	3.40	8.40
914.61	778.40	827.40	286.10	0.00	3.40	7.90
931.12	627.31	676.31	286.90	0.15	3.10	7.10
946.22	491.10	540.10	287.60	0.31	2.50	6.30
959.91	369.23	418.23	288.20	0.61	1.90	5.60
972.19	261.19	310.19	288.50	0.75	1.40	5.20
982.60	170.65	219.65	288.60	0.73	1.00	4.70
990.64	101.23	150.23	288.70	0.68	0.80	3.80
996.33	52.52	101.52	288.80	0.56	0.90	2.90
1000.12	20.17	69.17	289.00	0.54	0.80	2.00
1001.31	10.00	59.00	289.16	0.54	0.68	1.70
1002.25	2.00	51.00	289.33	0.54	0.48	1.20

Figure 1. A portion of MM5 data reduced from GRIB data.

NOTE: The top two lines are the latitude and longitude, respectively, of grid point. Columns of data (from left to right): pressure (mbar), height above ground (m), height above sea level (m), temperature (ºK), dew-point depression (ºK), *x*-component of wind vector (m/sec), and *y*-component of wind vector (m/sec).

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For this study, 12-h MM5 forecasts were used to produce nowcast analyses and make comparisons.

2.1.2 Surface Data

Surface meteorological data is contained in the ASCII text file named `sfcmet.d`. The file contains observational data of pressure, temperature, dew-point temperature, wind speed, and wind direction. Figure 2 shows a portion of `sfcmet.d` showing only temperature data.

```
Temperature (C)
51
   32.299999  -86.400002 12Apr 12:00      16.00
   32.330002  -85.000000 12Apr 11:55      16.00
   32.380001  -86.370003 12Apr 12:00      16.00
   32.520000  -84.930000 12Apr 11:53      17.00
   32.619999  -85.430000 12Apr 12:00      16.00
   32.630001  -83.599998 12Apr 12:00      16.00
   32.700001  -83.650002 12Apr 12:00      17.00
   32.919998  -85.970001 12Apr 12:00      16.00
   32.950001  -84.269997 12Apr 12:00      16.00
   33.020000  -85.070000 12Apr 12:00      16.00
   33.169998  -86.769997 12Apr 11:53      16.00
   33.369999  -84.550003 12Apr 12:00      16.00
   33.369999  -81.970001 12Apr 12:00      18.00
   33.529999  -82.519997 12Apr 12:00      13.00
   33.570000  -86.750000 12Apr 11:53      14.00
   33.580002  -85.849998 12Apr 11:53      16.00
   33.650002  -84.419998 12Apr 12:00      14.00
   33.779999  -84.519997 12Apr 12:00      16.00
   33.779999  -82.820000 12Apr 12:00      12.00
   33.880001  -84.300003 12Apr 11:53      13.00
   33.919998  -84.519997 12Apr 12:21      13.00
   33.950001  -83.320000 12Apr 12:00      12.20
   33.970001  -86.080002 12Apr 12:00      13.00
   33.980000  -83.970001 12Apr 12:00      12.00
   33.980000  -83.669998 12Apr 12:00      12.00
   34.020000  -84.599998 12Apr 12:00      13.00
   34.099998  -82.820000 12Apr 12:00      12.00
   34.119999  -84.529999 12Apr 11:53      14.00
   34.230000  -82.150002 12Apr 12:00      11.00
   34.270000  -86.849998 12Apr 12:00      12.00
   34.270000  -83.830002 12Apr 12:00      11.00
   34.349998  -85.169998 12Apr 12:00      14.00
   34.500000  -82.720001 12Apr 12:00       9.00
   34.650002  -86.949997 12Apr 12:00      11.00
   34.650002  -86.769997 12Apr 12:00      11.00
   34.669998  -82.870003 12Apr 12:00      10.00
   34.720001  -84.870003 12Apr 12:00      15.00
   34.849998  -82.349998 12Apr 11:53       8.00
   34.869999  -86.550003 12Apr 12:00      11.00
   34.880001  -82.220001 12Apr 12:00       8.00
   35.029999  -85.199997 12Apr 12:00      11.00
   35.220001  -83.419998 12Apr 12:00      13.00
   35.430000  -82.550003 12Apr 12:00       9.00
   35.430000  -81.930000 12Apr 12:00       8.00
   35.820000  -83.980003 12Apr 12:00      11.00
   35.950001  -85.080002 12Apr 12:00       8.00
```

Figure 2. A portion of the surface observation file, `sfcmet.d`, showing temperature only.

NOTE: Columns of data (from left to right): number of temperature observations, latitude, longitude, date, hour, and temperature (ºC) per observation.

2.1.3 Upper-Air Radiosonde Data

Upper-air data is contained in the file named `new_sound`, as shown in figure 3. Information about latitude, longitude, height above ground, date, hour of observation, and number of levels are given in the first three lines. The columns contain data on pressure (mbar), height above sea level (m), temperature (ºC), dew-point temperature (ºC), wind speed (knots), and wind direction (deg). Missing data is expressed as "-999.0." The file contains all radiosonde sounding data obtained from an area of 1,600 by 1,600 km^2—the nowcast analysis domain of 500 by 500 km^2 is located at the center.

```
                    thenmi@mn1:~/Nowcast_imets/HOTDATA
   33.3700    -84.5700    244.000
12Apr 12:00
   78
   977.0      244.0      16.0      13.1       2.0     110.0
   925.0      704.8      13.0      12.6    -999.0    -999.0
   885.0     1074.9      12.2      10.3    -999.0    -999.0
   872.0     1200.0    -999.0    -999.0      14.0     145.0
   850.0     1410.8      10.0       8.7      14.0     150.0
   840.9     1500.0    -999.0    -999.0      14.0     150.0
   832.0     1588.0       8.8       7.2    -999.0    -999.0
   815.0     1758.4       8.8       4.5    -999.0    -999.0
   811.0     1800.0    -999.0    -999.0      12.0     170.0
   785.0     2066.9       6.6       6.1    -999.0    -999.0
   782.0     2100.0    -999.0    -999.0      13.0     200.0
   754.5     2400.0    -999.0    -999.0      15.0     205.0
   727.1     2700.0    -999.0    -999.0      17.0     210.0
   700.0     2996.2       0.8       0.8      19.0     205.0
   674.3     3300.0    -999.0    -999.0      24.0     200.0
   657.0     3504.1       0.0      -4.1    -999.0    -999.0
   649.5     3600.0    -999.0    -999.0      23.0     200.0
   602.4     4200.0    -999.0    -999.0      21.0     215.0
   590.0     4358.1      -4.1     -11.1    -999.0    -999.0
   569.0     4642.5      -6.3     -16.3    -999.0    -999.0
   564.0     4711.4      -6.7     -18.7    -999.0    -999.0
   560.0     4767.0      -6.5     -30.5    -999.0    -999.0
   557.6     4800.0    -999.0    -999.0      21.0     225.0
   553.0     4865.2      -6.7     -36.7    -999.0    -999.0
   500.0     5642.2     -12.9     -47.9      19.0     230.0
   478.1     6000.0    -999.0    -999.0      21.0     235.0
   422.9     6900.0    -999.0    -999.0      37.0     230.0
   418.0     6980.7     -23.1     -41.1    -999.0    -999.0
   400.0     7301.8     -25.1     -52.1      38.0     230.0
   390.0     7500.0    -999.0    -999.0      38.0     225.0
   316.0     8967.3     -38.7     -60.7    -999.0    -999.0
   314.5     9000.0    -999.0    -999.0      42.0     220.0
   301.0     9300.0    -999.0    -999.0      37.0     215.0
   300.0     9321.7     -41.7     -51.7      40.0     220.0
   284.0     9692.3     -42.9     -47.0    -999.0    -999.0
   275.6     9900.0    -999.0    -999.0      51.0     205.0
   251.5    10500.0    -999.0    -999.0      52.0     210.0
   250.0    10537.5     -50.7     -54.2      50.0     205.0
   240.8    10800.0    -999.0    -999.0      55.0     210.0
   200.0    11959.2     -60.5     -64.1    -999.0    -999.0
   182.0    12540.2     -65.1     -68.7    -999.0    -999.0
   176.0    12746.8     -60.5     -64.6    -999.0    -999.0
   150.0    13758.6     -53.5     -67.5      30.0     240.0
   149.2    13800.0    -999.0    -999.0      31.0     240.0
   131.5    14700.0    -999.0    -999.0      41.0     230.0
```

Figure 3. A portion of the upper-air radiosonde sounding data file, `new_sound`.

NOTE: Columns of date (from left to right): pressure (mbar), height above sea level (m), temperature (ºK), dew-point temperature (ºK), wind speed (m/s), and wind direction (deg).

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2.2 Methodology

2.2.1 Three-Dimensional Analysis of MM5 and Upper-Air Data

The MM5 forecast data, as shown in figure 1, are interpolated to the three-dimensional nowcasting grids of a finer spatial horizontal grid resolution than that of the MM5 and to the sigma-z vertical coordinate used by the current IMETS Battlescale Forecast Model (BFM).

This vertical coordinate is defined as

$$z^* = \overline{H} \frac{z - z_g}{H - z_g}$$

(1)

where

z	=	the Cartesian vertical coordinate,
z_g	=	the ground elevation,
$\overline{H}$	=	the material surface top of the analysis in the z^* coordinate, and
H	=	the corresponding height in the z coordinate defined by $H = \overline{H} + z_{g\,max}$,

where

$z_{g\,max}$	=	the maximum value of the terrain elevation in the nowcast analysis domain.

Currently, the vertical extent of the nowcast analysis is fixed at 7000 m above the highest grid point of the domain.

The following procedures are taken to interpolate the raw MM5 forecast data to the three-dimensional grid defined as the nowcast analysis domain:

- Parameters, including temperature, mixing ratio, and horizontal wind components (u and v on the pressure level pk), are vertically interpolated to 20 pre-determined Cartesian-z vertical levels (zi, i = 1,20).

- Horizontal interpolation (to analysis i, j grid space) of each parameter on zi levels are performed for each parameter.

- An arbitrary parameter φ on zi is linearly interpolated to a z* level of the nowcasting grid as

$$\varphi(z^*) = \varphi_k + \frac{(\varphi_{k+1} - \varphi_k)}{(\zeta_{k+1} - \zeta_k)}(z_{st} - \zeta_k)$$

(2)

where z_{st} is the Cartesian height above sea level of z^*, calculated from eq 1 as

$$z_{st} = z_g + z^* \frac{\left(\overline{H} + z_{g\,\max} - z_g\right)}{\overline{H}} \tag{3}$$

and ζ_k is the height of the kth z_i level.

If there is no upper-air radiosonde sounding data available, then the three-dimensional data of $\varphi(z^*)$ determined by eq 2 is used as three-dimensional data for coupling with the surface field analyses.

If upper-air radiosonde sounding data are available at the time of analysis, the three-dimensional MM5 data calculated using the above procedures will first be composed with the upper-air radiosonde sounding data. At each sounding location, radiosonde data, such as horizontal wind vector components, temperature, and mixing ratio, are vertically interpolated to the z_i levels by using a linear interpolation method. At each z_i level, the successive correction method is then performed by using the MM5 three-dimensional data as background data. Finally, linear vertical interpolation from z_i to z_{st} is performed for each parameter and grid point. At this point, the composed upper-air univariate analyses are ready for coupling to the surface field univariate analyses by using MARIAH similarity theory.

2.2.2 Surface Data Analysis

Using the MM5 forecast as background data, univariate nowcasting analyses of surface temperature, dew-point temperature, and horizontal u and v wind vector components are conducted. The successive correction method that follows is used in this development.

If $\varphi_a(i, j)$ is the nowcast value at the grid point (i, j), and $\varphi_b(i, j)$ is the value of the MM5 background at the same grid point, then

$$\varphi_a(i, j) = \varphi_b(i, j) + \sum_{k=1}^{m} w_{k,ij}(\varphi_{o,k} - \varphi_{b,k}) \tag{4}$$

where

$\varphi_{o,k}$ is the observation at the kth location,

$w_{k,ij}$ is the weight for each observation,

$\varphi_{b,k}$ is the value of the background at the observation point derived by a bilinear interpolation method, and

m is the total number of observations.

The weighting factor is defined as

$$w_{k,ij} = \frac{1}{r^2_{k,ij}}$$ (5)

where $r_{k,ij}$ is the horizontal distance between the kth observation point and grid point (i, j).

The method is repeated in an iterative fashion, so that the background field is updated by the latest analysis after each iteration

$$\varphi_a(n+1) = \varphi_a(n) + \sum_{k=1}^{m} w_{k,ij}(\varphi_{o,k} - \varphi_{a,k}(n))$$ (6)

where

$\varphi_a(n)$ is the value of the analysis at the grid point after the nth iteration, and

$\varphi_{a,k}(n)$ is its value interpolated for the kth location after the nth iteration.

In this development, the iteration was repeated three times, for practical purposes, to obtain the final values. A future modification that could be explored would be to add a vertical "distance" component to the $r_{k,ij}$ term used in the weighting to account for elevation differences between grid point and observation terrain elevations.

2.2.3 Similarity Formulae, MARIAH

The equations and approach for determining the similarity scaling constants for wind, temperature and specific humidity, referred to as MARIAH (Rachele et al., 1995), are used to complete the coupling between the surface and upper-air meteorological analyses in order to produce the final three-dimensional analysis dataset. For practical purposes, it is assumed that the lowest layers above ground for the three-dimensional analysis data are fixed to the standard screening heights used for collecting most surface meteorological data (2 and 10 magl). Details of MARIAH can be found in Rachele et al. (1995); here, the approach is only briefly described.

Potential temperature θ, specific humidity q, wind speed magnitude V, and wind direction are calculated from the MM5 lowest sigma-P level data.

The scaling height z^* is calculated as

$$z^* = \frac{z_2 - z_1}{\ln(z_2 / z_1)} = \frac{\Delta z}{\Delta \ln z}$$ (7)

and

$$\Delta V = V(z_2) - V(z_1)$$
$$\Delta\theta = \theta(z_2) - \theta(z_1) \tag{8}$$
$$\Delta q = q(z_2) - q(z_1)$$

Here, z_1 is the height of the surface observation and z_2 is the height of the level above z_1. For θ and q, z_1 is 2 m, and for V, z_1 is 10 m.

Depending on the stability of the atmosphere near the surface, the profiles of temperature, specific humidity, and wind speed are determined in one of three ways.

For the Unstable case ($\Delta\theta / \Delta z < 0$), the Monin-Obukhov scaling length L is calculated as

$$L = \frac{\theta_v (\Delta V)^2}{[\Delta\theta + 0.61\theta\Delta q]g\Delta\ln z} \tag{9}$$

$$\phi_m = (1 - 15\frac{z}{L})^{-1/4} \tag{10}$$

$$\phi_H = (1 - 15\frac{z}{L})^{-1/2} \tag{11}$$

$$V_* = \frac{k\Delta V}{\phi_m \ln(z_2/z_1)} \tag{12}$$

$$\theta_* = \frac{k\Delta\theta}{\phi_H \ln(z_2/z_1)} \tag{13}$$

$$q_* = \frac{k\Delta q}{\phi_H \ln(z_2/z_1)} \tag{14}$$

Here, k is Karman constant (= 0.4).

Wind speed, potential temperature, and specific humidity at the height z_2 are given as

$$V(z_2) = V(z_1) + \frac{V^* \phi_m}{kz^*}\Delta z \tag{15}$$

$$\theta(z_2) = \theta(z_1) + \frac{\theta^* \phi_H}{kz^*}\Delta z \tag{16}$$

$$q(z_2) = q(z_1) + \frac{q^* \phi_H}{kz^*}\Delta z \tag{17}$$

9

For the stable case ($\Delta\theta / \Delta z > 0$),

$$L = \frac{\theta(z_2)(1+0.61q(z_2))(\Delta V)^2}{[\Delta\theta + 0.61\theta\Delta q]g\Delta z} - 5z_2 \qquad (18)$$

and

$$\phi_m = \phi_H = 1 + 5(z_2 / L) \qquad (19)$$

$$V(z_2) = V(z_1) + \frac{V_*}{k}[\ln(\frac{z_2}{z_1}) + 5\frac{z_2 - z_1}{L}] \qquad (20)$$

$$\theta(z_2) = \theta(z_1) + \frac{\theta_*}{k}[\ln(\frac{z_2}{z_1}) + 5\frac{z_2 - z_1}{L}] \qquad (21)$$

$$q(z_2) = q(z_1) + \frac{q_*}{k}[\ln(\frac{z_2}{z_1}) + 5\frac{z_2 - z_1}{L}] \qquad (22)$$

For the neutral case ($\Delta\theta / \Delta z = 0$),

$$V(z_2) = V(z_1) + \frac{V_*}{k}\ln(\frac{z_2}{z_1}) \qquad (23)$$

$$\theta(z_2) = \theta(z_1) + \frac{\theta_*}{k}\ln(\frac{z_2}{z_1}) \qquad (24)$$

$$q(z_2) = q(z_1) + \frac{q_*}{k}\ln\frac{z_2}{z_1} \qquad (25)$$

---

3. Example Over the Southeastern United States

To demonstrate the ability of the described nowcasting analysis method, it was applied to a domain located in the southeastern United States. Figure 4 shows the terrain elevation contours across the 500-by-500 km nowcast analysis domain (10-km resolution), centered at 34.44°N and 84.55°W. The MM5 forecasts were obtained directly from AFWA.
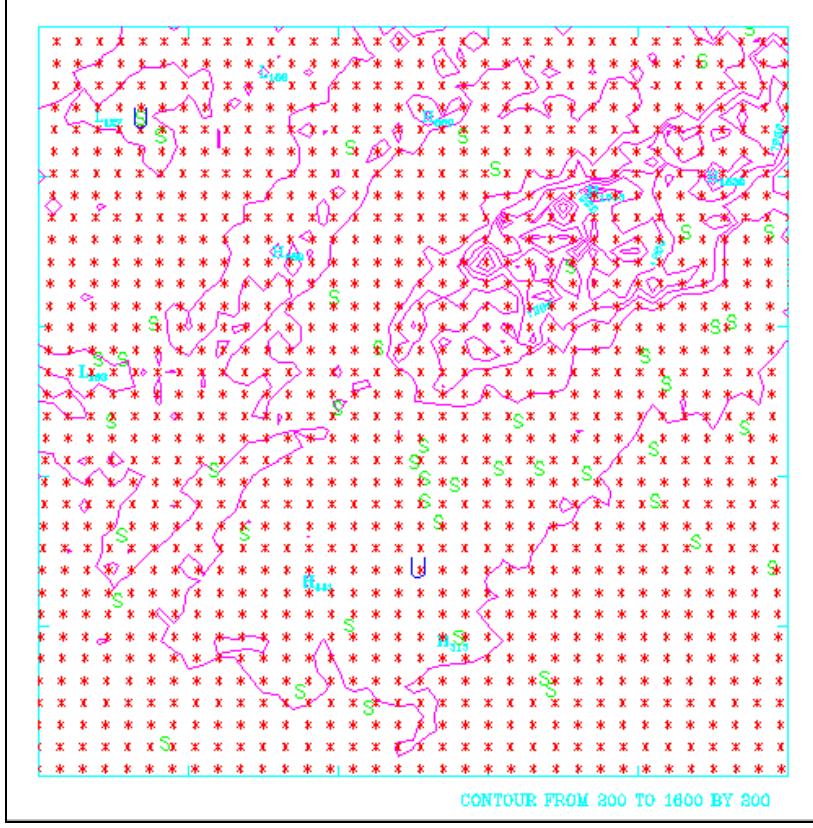
Figure 4. Terrain contours for the southeastern (SE) U.S. 500-by-500 km
nowcasting area, centered at 34.44ºN and 84.55ºW.

The "*" symbol represents the 15-km resolution MM5 grid-point locations, the letter "S" represents the locations of the surface meteorological observations, and the letter "U" represents the location of the upper-air radiosonde observations. A radiosonde site (Nashville, TN) is located in the northwestern part of the domain, while the other site (Peach Tree, GA) is located in the south-central part of the figure.

The data used in this case application were obtained for 1200 UTC on April 12, 2004.

Figure 5A shows the surface wind vector distribution forecasted by the 15-km resolution MM5. In figure 5A, the wind vectors at every other grid point are plotted for visual clarity; the maximum wind vector is 4.1 m/s. Figure 5B plots the observed surface wind vectors for the corresponding time.
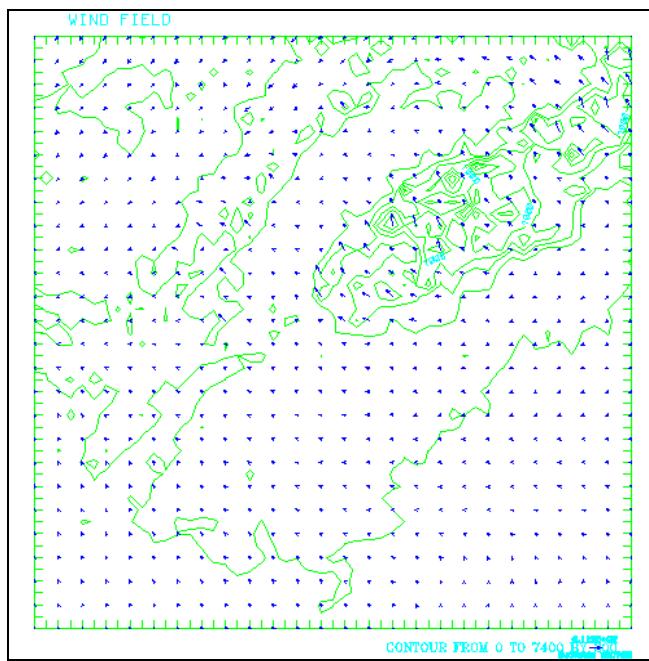
Figure 5A. Surface wind vector fields for the 10-km resolution
            SE U.S. domain, interpolated from MM5 15-km
            resolution forecast data, for 1200 UTC, April 12,
   2004.
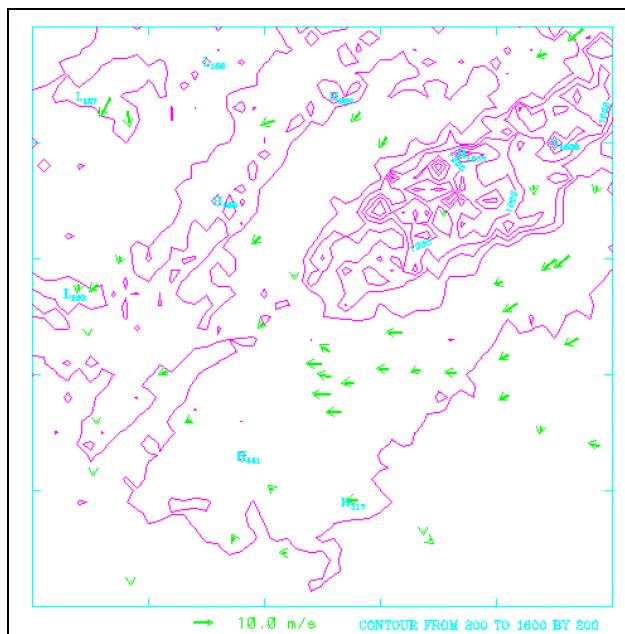
Figure 5B. Observed SE U.S. surface wind vectors at
            1200 UTC, April 12, 2004.

The nowcasting analysis result, generated by applying the successive correction method to the wind fields shown in figures 5A and 5B, is presented in figure 5C. The maximum wind vector in the figure 5C is 4.0 m/sec.
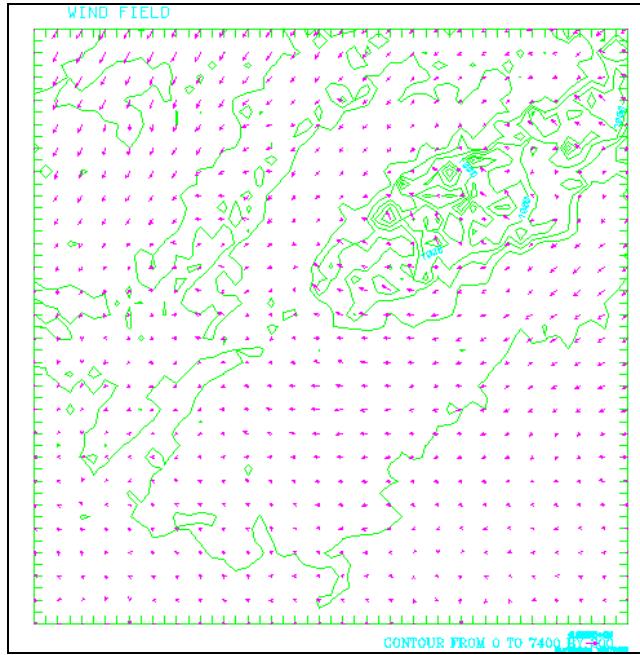
Figure 5C. Nowcast analysis of the SE U.S. domain surface
wind field, using the successive correction method
and the wind fields shown in figures 5A and 5B.

Figure 6A shows the surface temperature field forecasted by the 15-km resolution MM5, valid at 1200 UTC on April 12, 2004. The nowcast calculation, achieved by combining the successive correction method and MARIAH formulae using the MM5 forecast temperature field and the observed temperature data, resulted in the nowcast analysis temperature field shown in figure 6B.
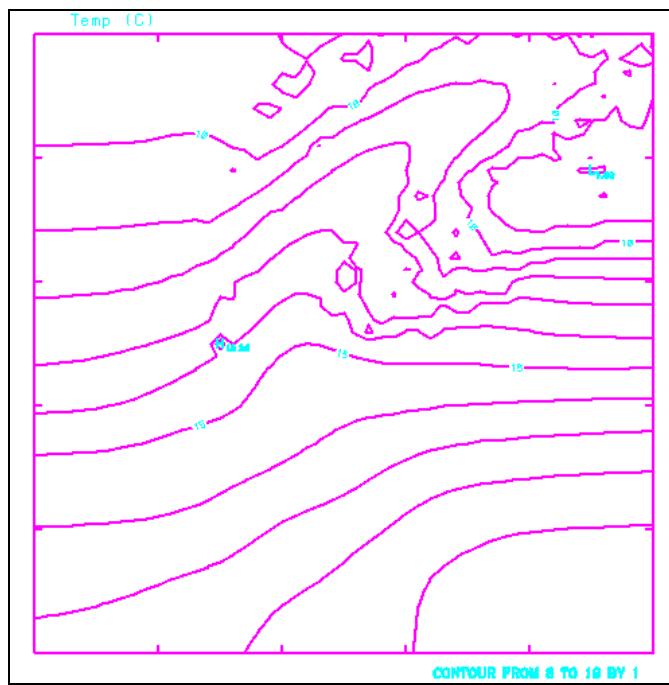
Figure 6A. Surface temperature field for the 10-km resolution SE U.S. nowcast domain, interpolated from MM5 15-km resolution forecast data for 1200 UTC, April 12, 2004.
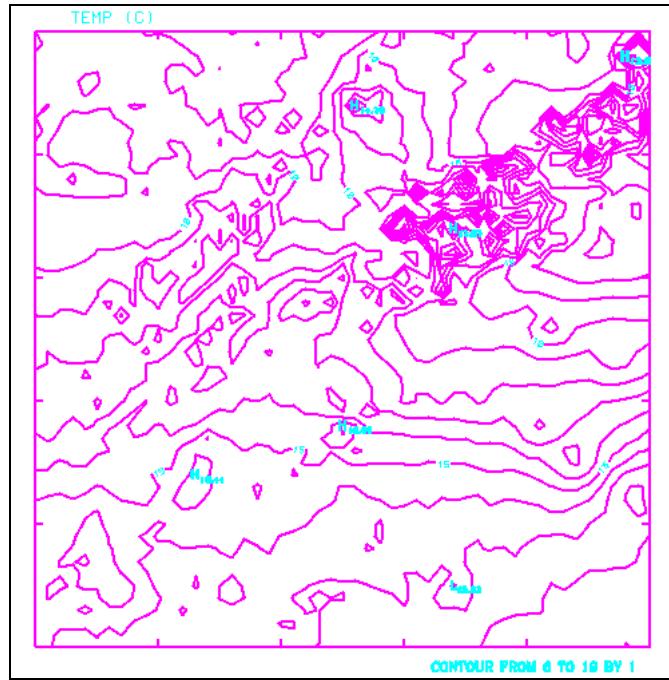
Figure 6B. Nowcast analysis of surface temperature, obtained from the successive corrections combination of MM5 forecast data and surface observation data for 1200 UTC, April 12, 2004.

This example uses upper-air radiosonde sounding data observed at both the Peach Tree and Nashville sites.

Figures 7A shows temperature and dew-point temperature, and figure 7B shows wind speed and direction, obtained for the Peach Tree radiosonde site. The three colored curves represent profiles generated from the 15-km MM5 forecast (red), the actual Peach Tree radiosonde observation (purple), and the successive corrections nowcast analysis (green).
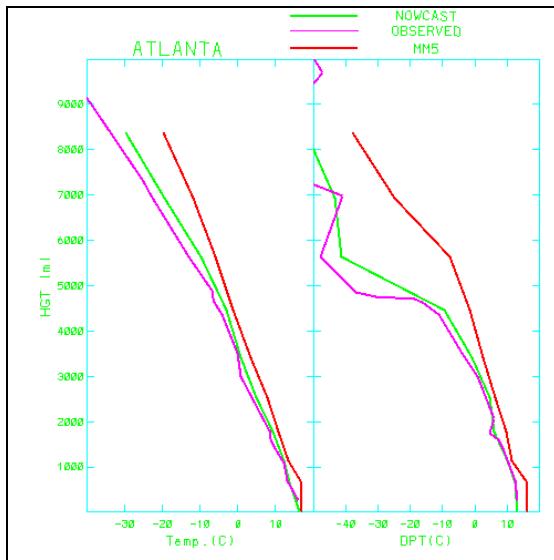
Figure 7A. Vertical distributions of temperature and dew-point temperature for the Peach Tree radiosonde site, generated from MM5, observed, and nowcast data, for 1200 UTC, April 12, 2004.
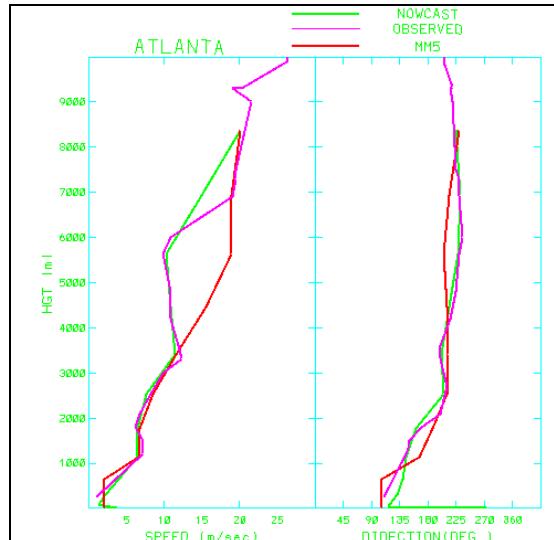
Figure 7B. Same as figure 7B, except for wind speed and direction.

Similar figures were obtained for the Nashville radiosonde site, but are not shown in this report.

Figures 5–7 clearly show that this method can bring three-dimensional fields of meteorological parameters forecasted by the MM5 closer to the actual values reported by observations.

4. Statistical Evaluation of the Nowcast Analysis Method Over the Utah Western U.S. Domain, Using MesoWest Surface Observation Data

In this section, the nowcast analysis method (for surface fields only) is compared statistically with observed data obtained from the MesoWest surface network, for a domain over the western U.S., centered on a location inside Utah. In addition, statistical evaluations are made for both the pure MM5 forecast and for a separate method based on the earlier BFM dynamic assimilation (or nudging) methodology.

The three different set of results being compared in this section are as follows:

1. Surface meteorological fields generated by the nowcast analysis method, using MM5, domain 2 (15-km resolution), 12-h forecasts as background data

2. 12-h forecasted surface meteorological fields from the MM5, domain 3 (5-km resolution)

3. Surface meteorological fields produced by the BFM nudging method, using a 3-h dynamic assimilation cycle (Henmi and Dumais, 1998)

In the above comparisons, a 5-km resolution grid was used to produce the final datasets.

4.1 Modeling Domains

The three different methods were applied to a 5-km horizontal resolution domain centered on Utah (fig. 8).
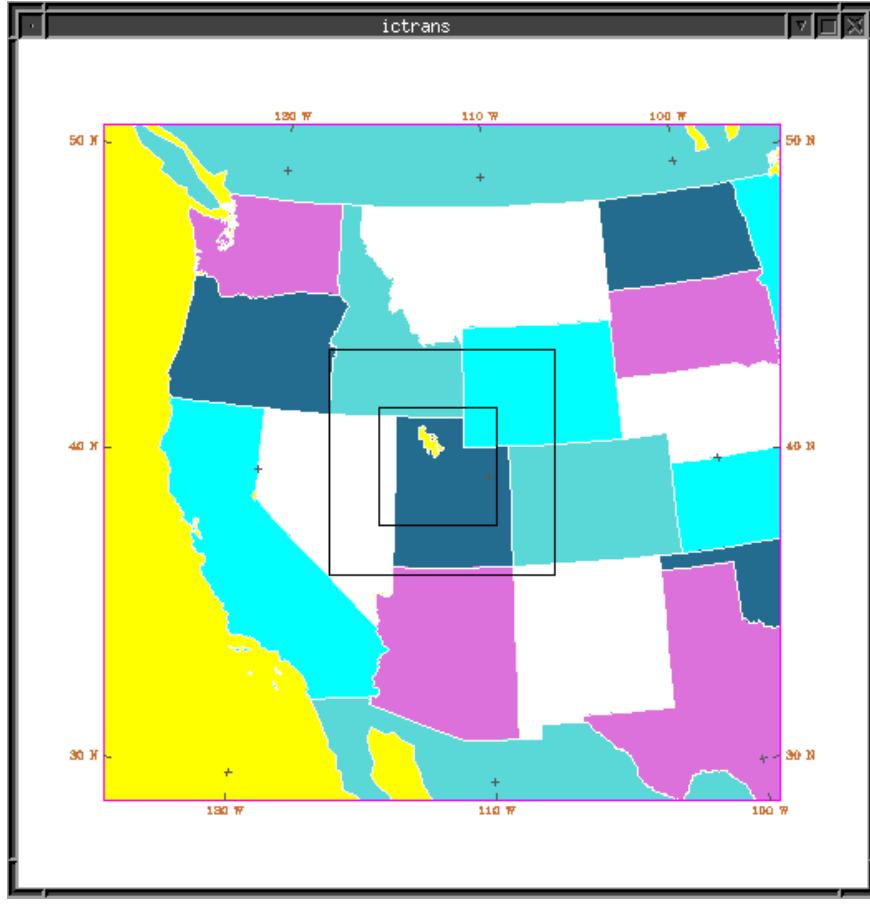
Figure 8. Geographical extent of the three MM5 computational nests.

The MM5 model was executed in a triple-nest configuration. The model domains 1 and 2 have a horizontal mesh size of 55-by-55 grid points, while the innermost model domain 3 has a horizontal mesh size of 85 by 85. The horizontal resolutions of each domain are 45, 15, and 5 km, respectively. For this study, the forecast fields for domain 2 were used as the background data for the nowcast analysis algorithm (and for the BFM nudging method), since 15 km is the smallest resolution of MM5 data that is typically available in IMETS.

Figure 9 shows the terrain contours across the grid domain used for the statistical comparisons, which has 51-by-51 grid points and a 5-km horizontal resolution. The letter "S" represents the location of MesoWest surface observation sites, whose data were used for producing the actual nowcast (and BFM nudging-based) analyses, and the symbol "*" represents those observation sites, whose data were used only to compare to the nowcast (or forecast/BFM nudging) analyses to produce the statistics (i.e., independent verification observations).
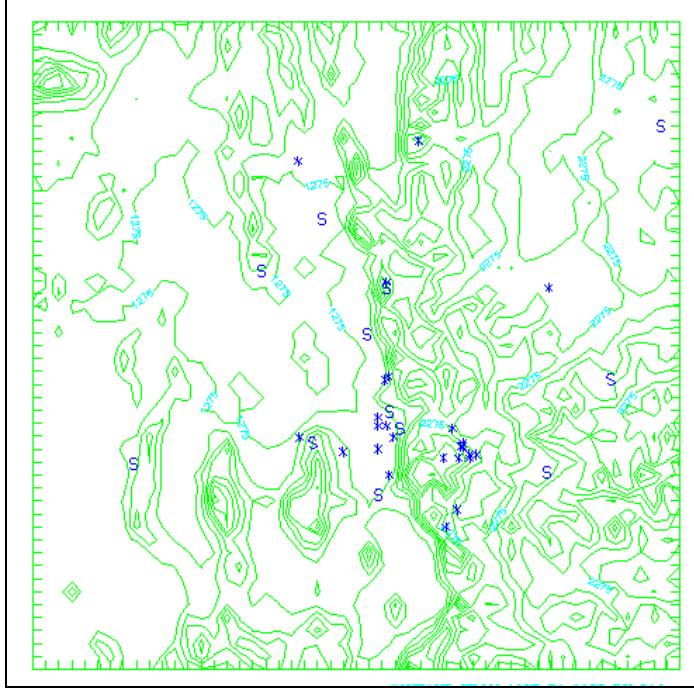
Figure 9. Terrain contours for the 5-km resolution Utah study
domain and the locations of MesoWest surface data.

4.2   Meteorological Data

As shown in figure 9, numerous MesoWest surface observational data sites are available. The data are publicly available from the University of Utah MesoWest cooperative anonymous file transfer protocol (FTP) site. MesoWest data, which is archived daily at ARL into an ASCII file called `total.dat`, includes observations taken over the past 24-h period, in 15-min intervals, for the entire western United States. A detailed description of the MesoWest data can be found in Horel et al. (2002).

The National Center for Environmental Prediction (NCEP) Aviation Model (AVN) provides global gridded forecast information at a 1° resolution. These data were used for initialization and time-dependent lateral boundary conditions for the locally run MM5 model. The AVN forecast data initialized at 1800 UTC were used for this study and were obtained through the anonymous FTP site at NCEP. The use of AVN (now called GFS) is consistent with the external model used by AFWA to provide lateral boundary conditions for its operational MM5 runs.

Datasets were collected for two different study periods, during which successive correction nowcast analysis, BFM nudging assimilation, and MM5 forecast data were generated and statistically analyzed for the following periods:

- August 1 through 21, 2003, for 17 days
- December 31, 2003 to January 28, 2004, for 17 days

MM5 15-km resolution forecast data, as shown in figure 1 and used for analysis background data, are stored at output frequency of every three hours (0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC). Similarly, `sfcmet.d` surface data files, as shown in figure 2, are made every three hours, corresponding to the MM5 output hours listed above.

4.3 Statistical Parameters

The following statistical parameters were calculated for evaluating the quality of the successive corrections nowcast analysis, BFM nudging assimilation, and MM5 5-km resolution, 12-h forecast datasets:

- Mean difference (MD)
- Mean absolute difference (AD)
- Root mean square error (RMSE)
- Root mean square vector error (RMSVE)
- Correlation coefficient (CC)
- Mean wind direction difference (MWDDF)

Details of these parameters are described in Henmi (2003).

For this report, these statistical parameters were calculated separately for the two different study periods, inclusive of all 17 days and all analysis periods (8) per day.

4.4 Evaluation Results

Statistical parameters were calculated between the surface nowcast analysis (and MM5 forecast/BFM nudged) data and surface observation data (after interpolation to the 5-km resolution study domain) and were obtained at the sites marked using the symbol "*", as shown in figure 9. Tables 1–3 show the values of statistical parameters calculated for the period in August 2003.

Statistical parameters calculated for the period in January 2004 are shown in tables 4–6.

Table 1. Statistical parameters between the successive corrections nowcast surface analysis (using MM5 15-km resolution, 12-h forecast background fields) and surface observation data for August 2003 data.

	MD	AD	RMSE	CC
Temperature (ºC)	-1.0	3.0	3.9	.82
Dew-point temperature (ºC)	-0.9	2.3	3.2	.75
Wind speed (m/sec)	-0.9	1.9	2.5	.36
Wind vector x-component (m/sec)	1.1	2.1	3.0	.13
Wind vector y-component (m/sec)	-0.5	2.1	2.7	.57

NOTE: RMSVE = 4.0 m/sec, MWDDF = 49º

Table 2. Statistical parameters between the 12-h forecast surface data from the 5-km resolution MM5, domain 3, and surface observed data for August 2003 data.

	MD	AD	RMSE	CC
Temperature (ºC)	-1.7	3.1	3.9	.81
Dew-point temperature (ºC)	4.2	5.2	7.1	.27
Wind speed (m/sec)	0.8	2.1	2.7	.36
Wind vector x-component (m/sec)	0.7	2.3	3.3	.03
Wind vector y-component (m/sec)	1.4	2.6	3.3	.52

NOTE: RMSVE = 4.6 m/sec, MWDDF = 53º

Table 3. Statistical parameters between the BFM nudging assimilated surface fields (using MM5 15-km resolution, 12-h forecast background fields) and surface observed data for August 2003 data. The BFM assimilation period was 3 h.

	MD	AD	RMSE	CC
Temperature (ºC)	-2.3	3.3	3.9	.85
Dew-point temperature (ºC)	3.8	4.3	5.4	.60
Wind speed (m/sec)	-1.1	1.9	2.5	.44
Wind vector x-component (m/sec)	0.0	1.8	2.5	.20
Wind vector y-component (m/sec)	0.1	2.1	2.8	.48

NOTE: RMSVE = 3.7 m/sec, MWDDF = 54º

Table 4. Same as table 1, except for January 2004 data.

	MD	AD	RMSE	CC
Temperature (ºC)	-2.0	3.7	6.9	.57
Dew point temperature (ºC)	-0.4	2.5	6.2	.60
Wind speed (m/sec)	-0.4	1.9	2.9	.35
Wind vector x-component (m/sec)	0.5	1.7	2.6	.28
Wind vector y-component (m/sec)	-0.8	2.0	2.9	0.40

NOTE: RMSVE = 3.9 m/sec, MWDDF = 55º

Table 5. Same as table 2 except for January 2004 data.

	MD	AD	RMSE	CC
Temperature (ºC)	0.8	3.6	6.9	0.50
Dew point temperature (ºC)	0.5	4.9	8.2	0.39
Wind speed (m/sec)	1.6	2.6	3.4	0.35
Wind vector x-component (m/sec)	1.1	2.0	3.2	0.18
Wind vector y-component (m/sec)	0.4	2.4	3.3	0.50

NOTE: RMSVE = 4.5 m/sec MWDDF = 42º

Table 6. Same as table 3 except for January 2004 data.

	MD	AD	RMSE	CC
Temperature (C)	0.8	3.1	6.4	0.55
Dew point temperature (C)	-0.1	2.9	6.4	0.55
Wind speed (m/sec)	-0.2	1.8	2.6	0.46
Wind vector x-component (m/sec)	-0.1	1.6	2.5	0.30
Wind vector y-component (m/sec)	0.4	1.9	2.7	0.48

NOTE: RMSVE = 3.6 m/sec, MWDDF = 43º

The statistical results shown in tables 1–6 were obtained by combining the data over all eight daily analysis periods (0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC.

Figures 10 and 11 are scatter diagrams for temperature—the first compares the successive corrections nowcast analysis results with observation data, and the second compares the 12-h forecast data from the MM5, domain 3 (5-km resolution), with observation data. All diagrams are for surface data only and for results on the Utah 5-km resolution grid mesh. Similarly, figures 12 and 13 are the scatter diagrams for dew-point temperature, and figures 14 and 15 are the scatter diagrams for wind speed. These figures are for the period in August 2003.
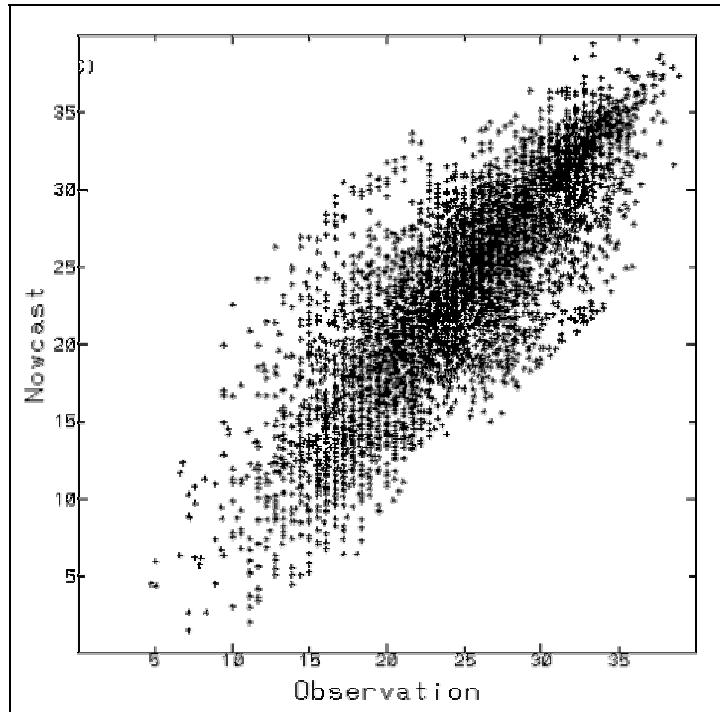
Figure 10. Scatter diagram between successive corrections nowcast analysis surface temperature data with and surface temperature observations, for the period in August 2003 over Utah domain.
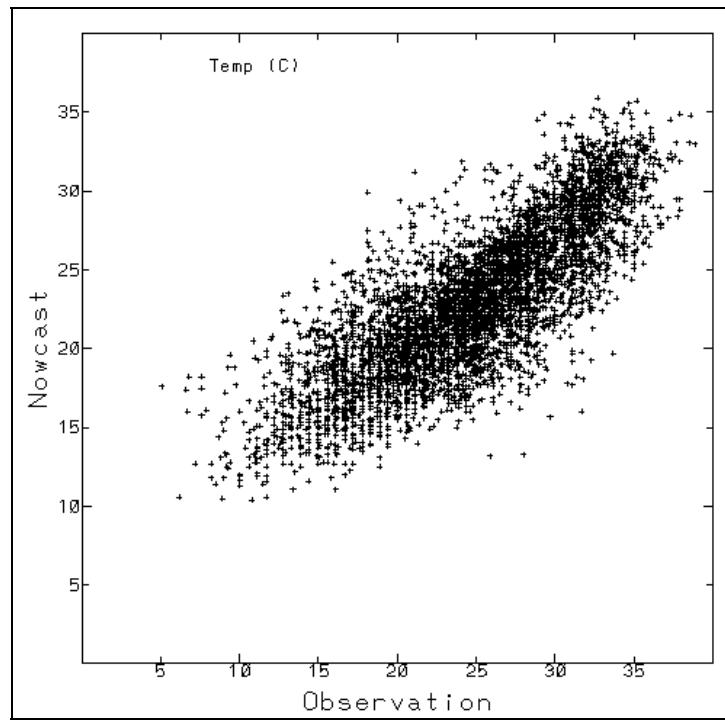
Figure 11. Scatter diagram between pure 12-h MM5, 5-km resolution
forecast surface temperature data and surface temperature
observations, for the period in August 2003 over Utah
domain.
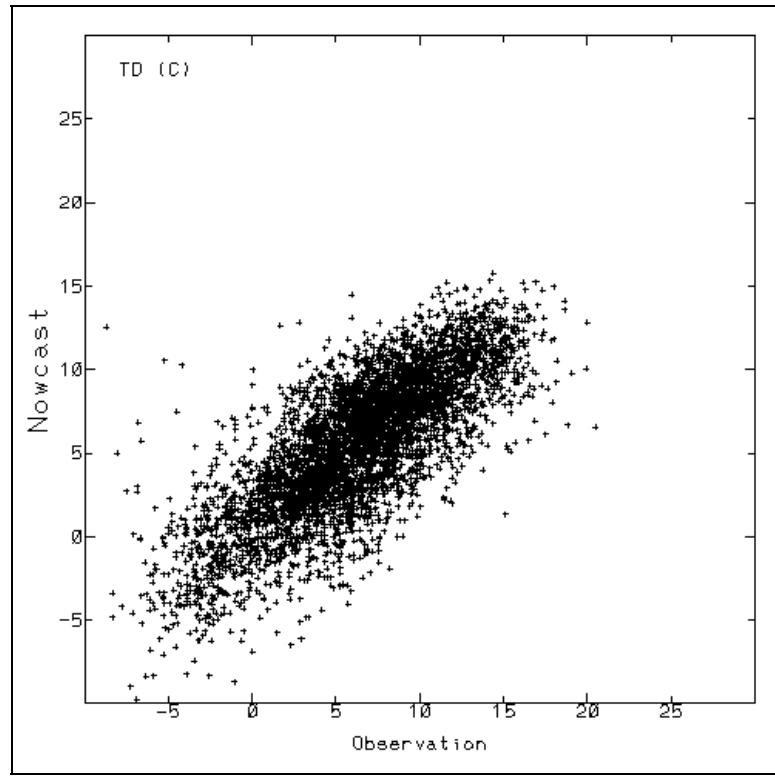
Figure 12. Same as figure 7, except for surface dew-point temperature.
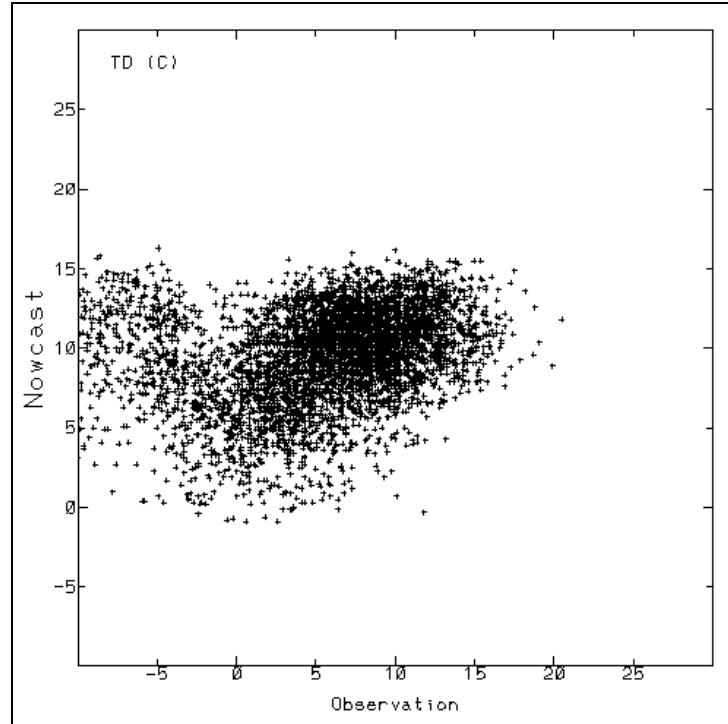
Figure 13. Same as figure 8, except for surface dew-point temperature.
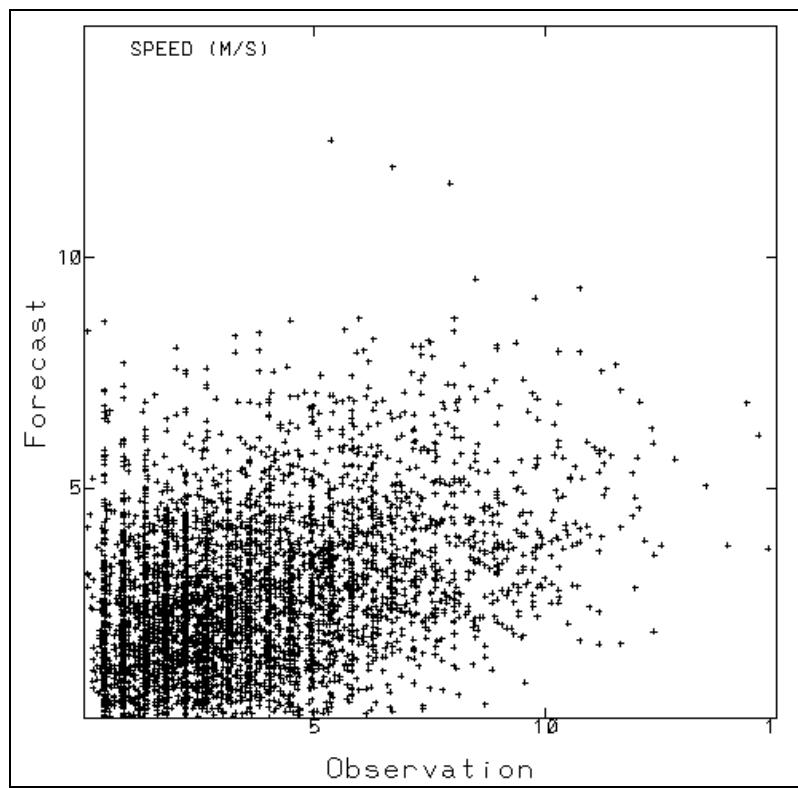
Figure 14. Same as figure 7, except for surface wind speed.
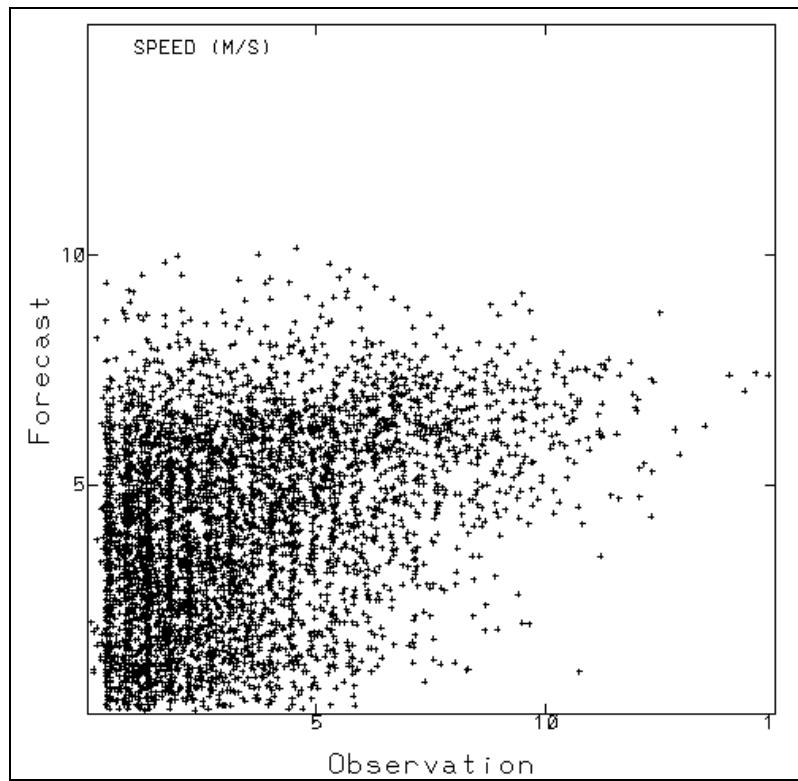
Figure 15. Same as figure 8, except for surface wind speed.

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Comparisons of tables 1-6 and figures 10-15 show that meteorological fields results can be improved by applying the successive corrections nowcast analysis method, beyond the results that an earlier-run, high-resolution numerical weather prediction (NWP) model can produce. However, over extremely complex terrains, such as the Utah study domain, the current method indicates only a limited potential for vastly improving surface meteorological fields (especially winds). In a similar study over Oklahoma, where the terrain features were not as complex (Sauter et al., 2001), results using this method produced far improved surface meteorological fields over the coincident NWP model forecast calculations.

The following time series of the statistical parameters (figs. 16–23) show MD, CC, AD, RMSVE, and MWDDF, calculated for every three hours of the diurnal cycle, using all available data for the 5-km resolution Utah domain. Figures 16–19 are for the period in August 2003, and figures 20–23 are for the period in January 2004. In these figures, the statistical parameters calculated for the three different methods (successive corrections nowcast analysis; 5-km resolution, 12-h MM5 forecasts; and BFM nudging assimilation over a 3-h period) are distinguished using three different colored lines.
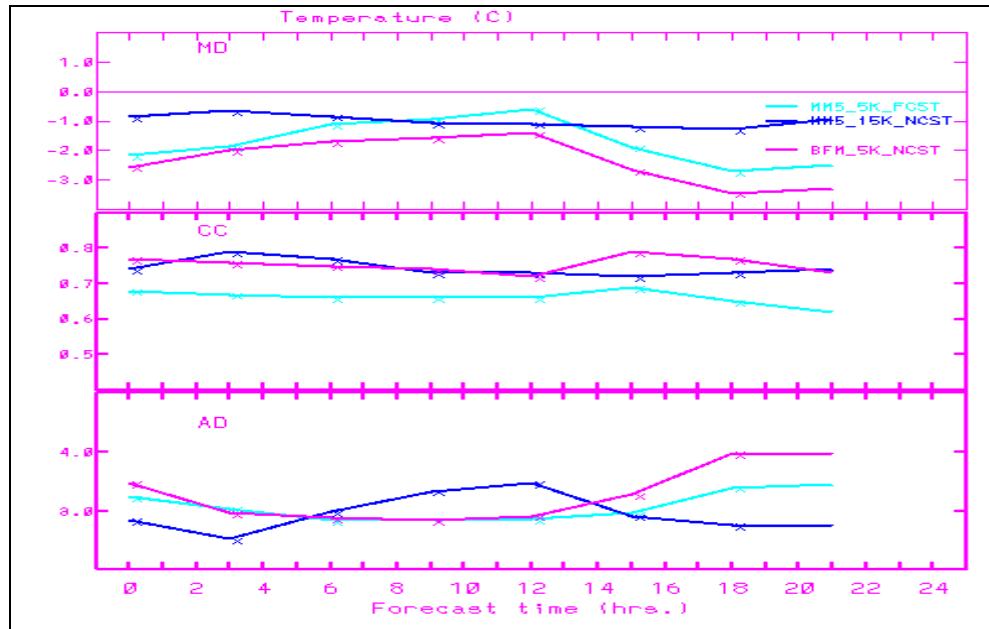
Figure 16. Time series of statistical parameters for all methods (MD, CC, and AD), for surface temperature, for the period in August 2003 in the Utah domain.
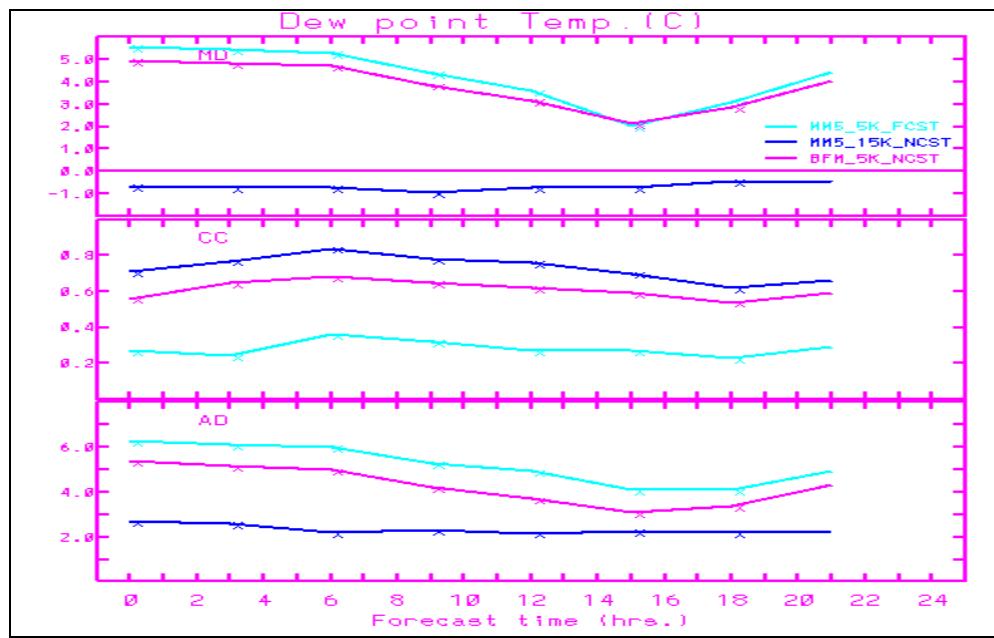
Figure 17. Same as figure 16, except for surface dew-point temperature.
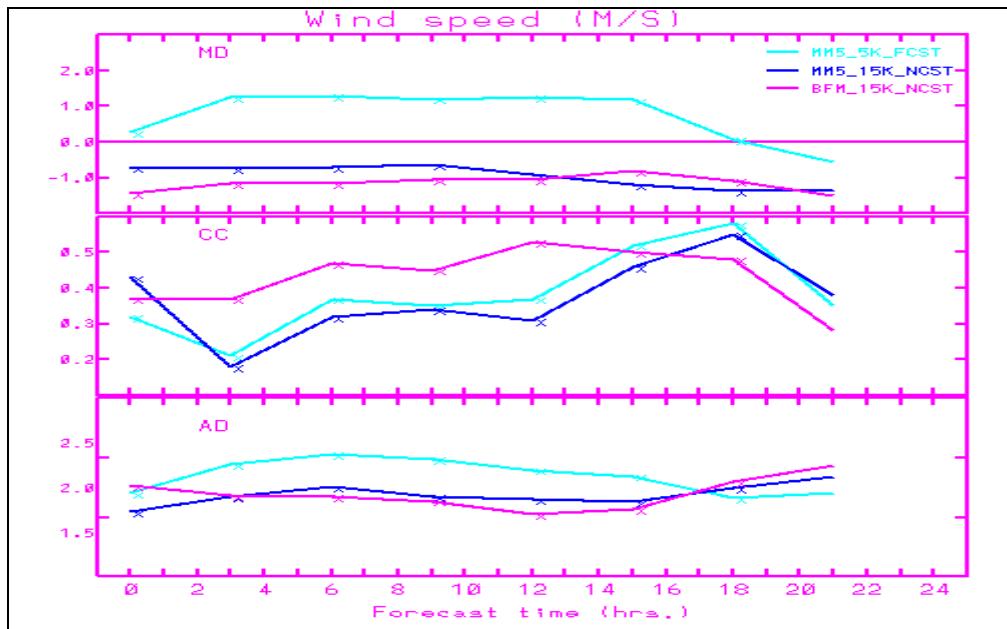
Figure 18. Same as figure 16, except for surface wind speed.
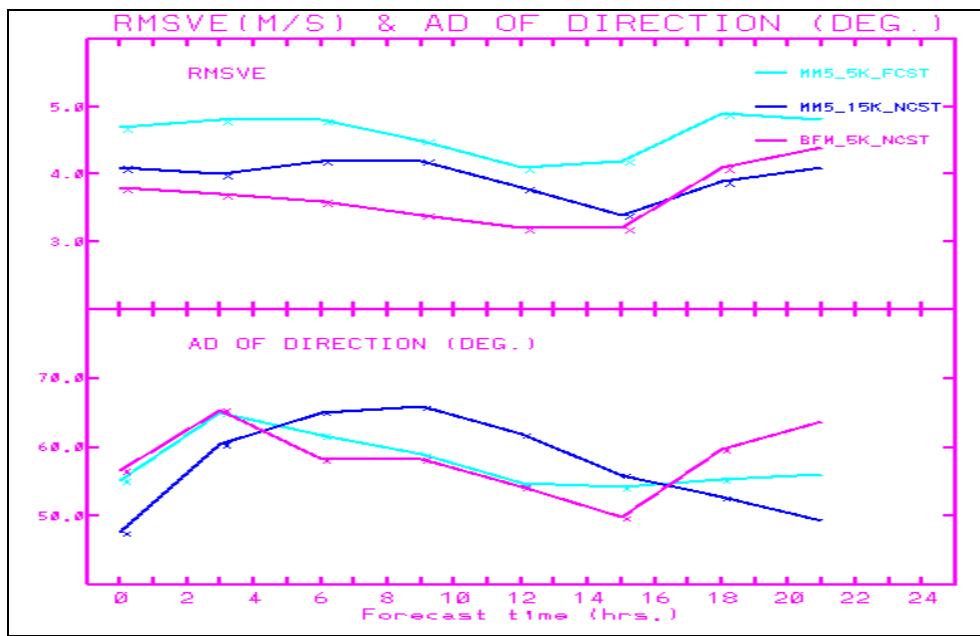
Figure 19. Same as figure 18, except for RMSVE and MWDDF.
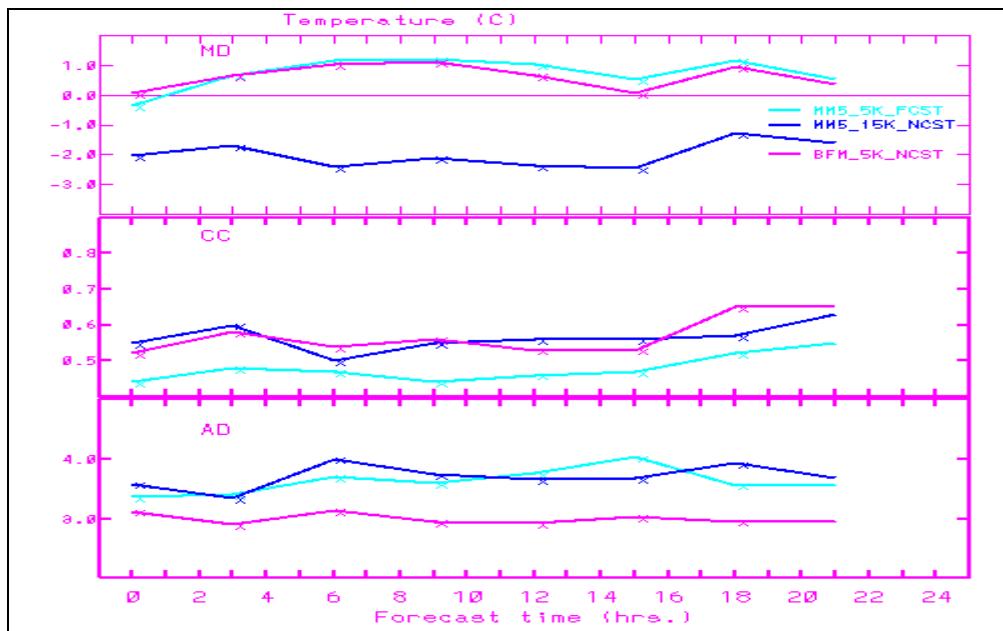
Figure 20. Time series of the statistical parameters for all methods (MD, CC, and AD), for surface temperature, for the period in January 2004 in the Utah domain.
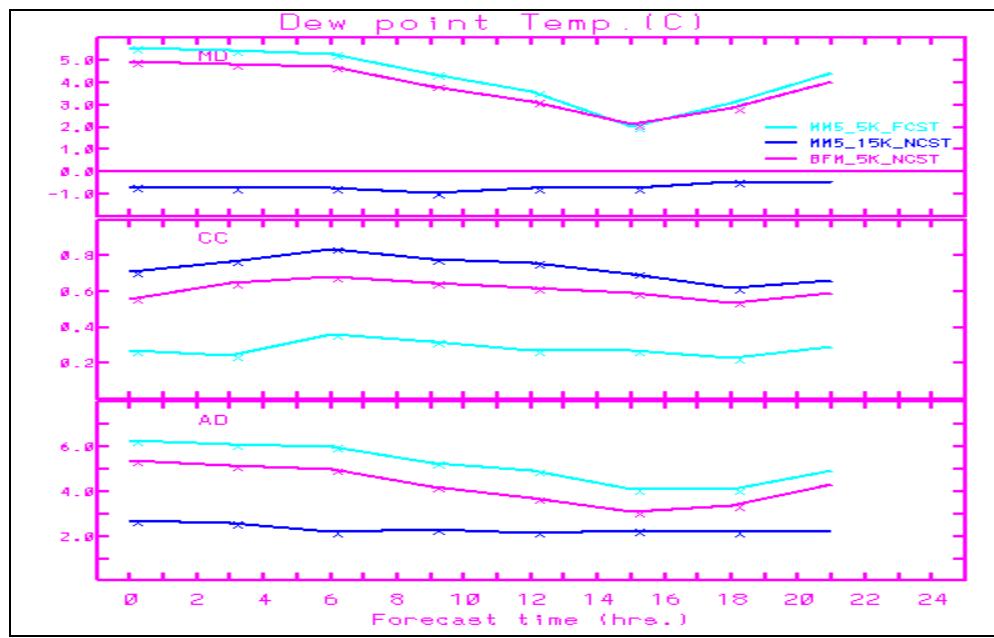
Figure 21. Same as figure 20, except for surface dew-point temperature.
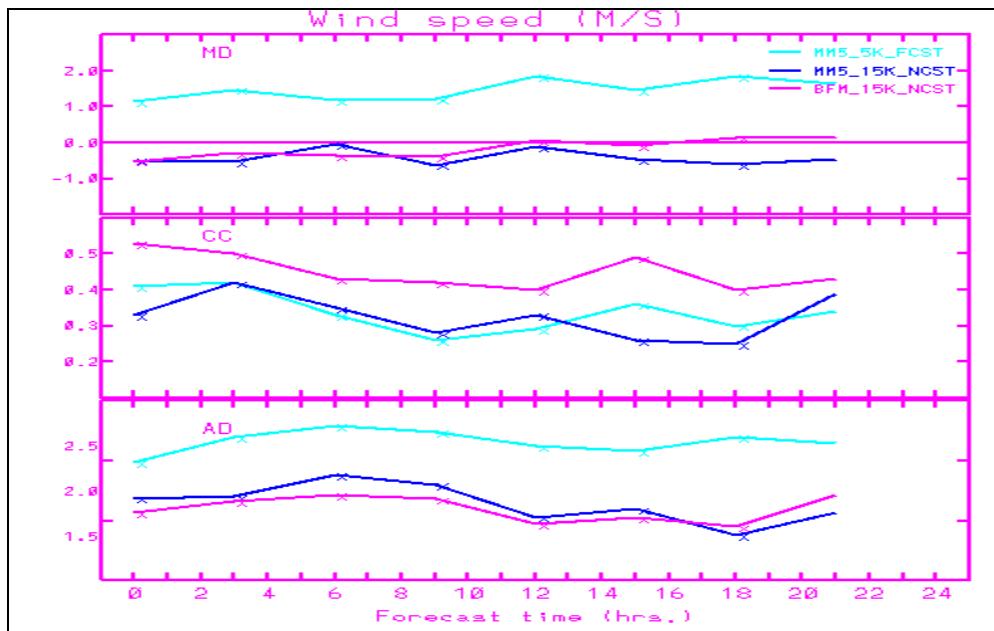

Figure 22. Same as figure 20, except for surface wind speed.
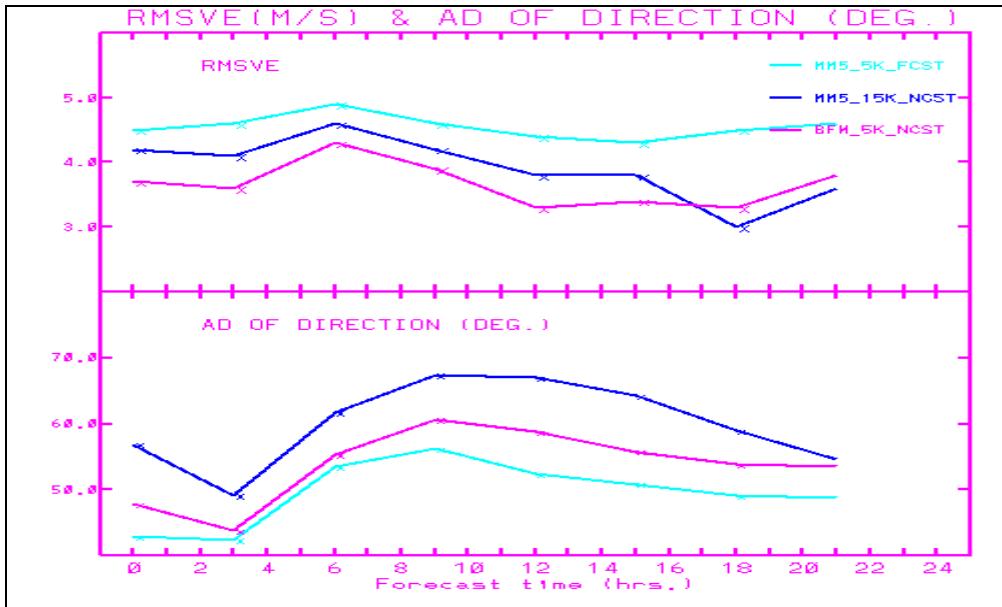
Figure 23. Same as figure 22, except for RMSVE and MWDDF.

As seen from these figures, both the successive correction nowcast analysis and the BFM nudging assimilation methods (which incorporate recent local observations into their solutions) clearly produced better statistical results than the pure 12-h forecasts obtained from the MM5, domain 3 (5-km resolution). The differences between the nowcast analysis and BFM nudging methods appear to be small statistically. It is worth noting that, during both periods, the statistical parameters obtained by all three methods were not significantly high. As seen in the statistical parameters of forecast results by MM5, domain 3, the MM5 did not perform well over the complex domain of Utah for either the warm (August 2003) or the cold (January 2004) period.

5.   Concluding Remarks

This report focuses on a nowcast analysis method, based on successive corrections and developed to use MM5 forecast fields as background data to combine surface and upper-air radiosonde observation data (Henmi, 2003), which has been modified for easier integration into the U.S. Army IMETS. This method utilizes MM5 GRIB forecast data, surface observations, and upper-air radiosonde observations similar to those currently obtained from the AFWA in IMETS. This method starts by composing and univariately analyzing two different sets of data: first, the surface observations and the corresponding MM5 surface forecast data, then the upper-air radiosonde sounding data and the MM5 forecast data. After these two steps, the similarity theory formulae, MARIAH, are used to couple the surface data univariate analysis fields with the

corresponding upper-air analysis fields, by calculating the meteorological parameters at the levels near the ground using the MARIAH formulae.

The usefulness of the method was demonstrated by applying it to a domain centered in the southeastern United States, for which MM5 GRIB forecast data, surface observations, and upper-air radiosonde observations were available from AFWA.

Evaluation and comparison studies of three different methods were conducted over a 250-by-250 km^2 domain in Utah, and the results of each method were statistically comparing with the Utah MesoWest surface data. The three different methods compared were as follows:

- Successive corrections nowcast analysis data, which used the MM5, domain 2 (15-km resolution), 12-h forecasts as background data
- Pure 12-h forecast data produced by the MM5 domain 3 (5-km resolution)
- BFM nudging assimilation method, using a 3-h assimilation period

Two observation datasets, for August 2003 and January 2004, were statistically compared with the above three methods.

The two non-forecast methods produced superior statistical results as compared to the pure forecast method; however, there were no significant statistical differences between the two non-forecast method datasets themselves. Statistical results showed that nowcasting of the temperature field can be accomplished more accurately than nowcasting of the dew-point temperature and wind fields. Over a complex terrain, such as in the model domain used for this study, forecasts and nowcasts of wind fields proved to be difficult, probably due to inhomogeneous distribution of observation sites and the limitations of the forecast model. It is essential to have better forecast data as background data in order to use the nowcast analysis method more effectively.

References

Grell, G.A.: Dudhia, J.; Stauffer, D.R. *A Description of the Fifth Generation Pennsylvania State University/NCAR Mesoscale Model (MM5)*; NCAR/TN 398+STR; National Center for Atmospheric Research, 1994

Henmi, T. *Nowcasting Surface Meteorological Parameters Using Successive Correction Method*; ARL-TR-2898; U.S. Army Research Laboratory: White Sands Missile Range, NM, 2002.

Henmi, T. *Development of a Nowcasting Method for Three-Dimensional Meteorological Data*: Preliminary Report, ARL-TR-3120; U.S. Army Research Laboratory: White Sands Missile Range, NM, 2003.

Henmi, T.; Dumais, R. *Description of the Battlescale Forecast Model*; ARL-TR-1032; U.S. Army Research Laboratory: White Sands Missile Range, NM, May 1998.

Horel, J.; Splitt, M.; Dunn, L.; Pechmann, J.; White, B.; Ciliberti, C.; Lazarus, S.; Slemmer, J.; Zaff, D.; Burks, J. MESOWEST: Cooperative Mesonets in the Western United States. *Bulletin of the American Met. Soc.* **2002**, *83*, 211–225.

Rachele, H.; Tunick, A.; Hansen, F.V. MARIAH: A Similarity-Based Method for Determining Wind, Temperature, and Humidity Profile Structure in the Atmospheric Surface Layer. *J. of Applied Met.* **1995**, *34*, 1000–1005.

Sashegyi, K.D.; Madala, R.D. Initial Conditions and Boundary Conditions, Mesoscale Modeling of the Atmosphere. *AMS Met. Monographs* **1994**, *25* (47) 1–12.

Sauter, B.; Henmi T.; Dumais, R.: Comparing Nowcasting Methods Using Oklahoma Mesonet Data. *Proceedings of the Battlespace Atmospheric and Cloud Impacts on Military Operation (BACIMO) Conference 2001*, July 2001.

Acronyms

AD	Mean Absolute Difference
AVN	Aviation Model
BFM	Battlescale Forecast Model
CC	correlation coefficient
FTP	file transfer protocol
MD	mean difference
MM5	Penn-State/NCAR Mesoscale Model version 5
MWDDF	mean wind direction difference
NCAR	National Center for Atmospheric Research
RMSE	root mean square error
RMSVE	root mean square vector error
SE	southeastern

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